

Ultra-Deepwater Production Systems Technical Progress Report

October 1, 2003 - September 30, 2004

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Title Page

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Abstract:

This report includes technical progress made during the period October, 2003 through September, 2004. At the end of the last technical progress report, the subsea processing aspects of the work program had been dropped due to the lack of commercial opportunity within ConocoPhillips, and the program had been redirected towards two other promising deepwater technologies: the development and demonstration of a composite production riser, and the development and testing of a close-tolerance liner drilling system. This report focuses on these two technologies.

Composite Production Riser:

The composite production riser project has progressed through the design verification testing phase, and manufacturing of field joints has begun. The testing program yielded a large amount of data that allowed to accurately calibrate the computer model, as well as identifying a number of technical improvement opportunities, most of which were implemented in the final field joint design. Test samples demonstrated very high load capabilities: 25,716 psi internal pressure and 2,400 kips axial tension. Field deployment on the Magnolia deepwater TLP in the Gulf of Mexico is now forecasted to take place late 2004/early 2005.

Close-Tolerance Liner Drilling: At the beginning of this reporting period, ConocoPhillips had selected Tesco and Baker Oil Tools to help in the work to develop the system. The design work was underway on the main components of the drilling system. During this reporting period, this design work was completed, the system was built, component testing was performed, and cased-hole and open-hole testing was completed on the system.

The testing program is discussed, and it was largely successful. The system functioned and tested as designed, but mechanical problems unrelated to the liner drilling system were encountered which led to failures within the liner hanger running tool and liner hanger, and testing was stopped. In the interim, ConocoPhillips's deepwater drilling program was terminated, and further supplemental funding could not be secured, so the repairs were not made and further testing did not occur.

In conclusion, it was proven that the close tolerance liner drilling system works as designed. Relatively simple mechanical enhancements are needed before the tool is commercially viable. In the absence of a deepwater drilling program in the Gulf of Mexico, ConocoPhillips' interest is low. Extensive sharing of the progress of the project has been done, and Industry interest is moderate at this time. Unless it is dramatically increased, however, no further work on the system will likely occur. ConocoPhillips is now working to generate that interest.

Table of Contents:

1. Title page
2. Disclaimer
3. Abstract
4. Table of contents
5. List of Graphical Materials
6. Introduction
7. Executive Summary
8. Results and Discussion
9. Conclusion

List of Figures:

Composite Production Riser

- Figure CPR 1 – Initial composite joint design
- Figure CPR 2 – Composite joint section (pin end)
- Figure CPR 3 – Example of FE model mesh
- Figure CPR 4 – Metal assembly
- Figure CPR 5 – Completed composite riser joint
- Figure CPR 6 – Pin/MCI assembly fitted to primary liner
- Figure CPR 7 – Secondary liner section being wrapped over primary liner, dry fiber and backing strips
- Figure CPR 8 – Secondary liner welds
- Figure CPR 9 – Completed metal assembly loaded onto winding cart
- Figure CPR 10 – Spraying Polyurea layer
- Figure CPR 11 – Polyurea machined into seal groove
- Figure CPR 12 – Rubber seal clamped in groove
- Figure CPR 13 – Pre-preg axial fiber strips applied
- Figure CPR 14 – Hoop fiber filament winding
- Figure CPR 15 – Composite application complete
- Figure CPR 16 – Impact protection foam installation
- Figure CPR 17 – Completed joint

Close Tolerance Liner Drilling System

- Figure CTLD 1 – Configuration of close tolerance liner drilling system
- Figure CTLD 2 – Dynamic Casing Seal assembly schematic
- Figure CTLD 3 – DCS Test fixture
- Figure CTLD 4 – “Bouncing Betty” Connector Fatigue testing apparatus
- Figure CTLD 5 – Stabbing the liner hanger into the 11-3/4” casing
- Figure CTLD 6 – Very little wear evident after the cased hole testing
- Figure CTLD 7 – Internal mechanism in liner hanger setting tool plugged with barite
- Figure CTLD 8 – Missing DCS wear buttons
- Figure CTLD 9 – Picking up the assembly for the open hole test
- Figure CTLD 10 – Gumbo packed around stabilizer and on top of liner hanger
- Figure CTLD 11 – New spherical wear pads on DCS
- Figure CTLD 12 – Missing ZXP seal after Open Hole Test
- Figure CTLD 13 – Inner Annulus Valve stops flow up the liner

Introduction:

The report herein is a summary of technical progress of two projects to demonstrate hydrocarbon drilling and production methods applicable to deep and ultra deepwater field developments in the Gulf of Mexico and other like applications around the world. This work advances technology that could lead to more economic development and exploitation of reserves in ultra-deep water or remote areas. In some cases, these technologies may be enabling: allowing for economic production where conventional technology simply cannot. Reserves in these areas can add significantly to reducing the United States dependence on foreign oil supplies. Importantly, both projects are considered as first steps in their respective technology application areas which, once proven, could lead to wide industry uptake and expansion of their applicabilities.

Executive Summary:

There are two remaining key components of our joint study and technology development efforts that will be described. The benefits of each with regard to technology enhancement and technology enablers in deep and ultra-deepwater hydrocarbon basins with particular emphasis on the Gulf of Mexico potential application will also be described. The areas to be addressed are Production Riser Demonstration planned for late 2004, and Close Tolerance Liner Drilling technology development and demonstration.

Composite Production Riser

The Composite Production Riser project was initiated as a joint industry project by ConocoPhillips, Kvaerner Oilfield Products and ChevronTexaco in March 2003, with financial support from the United States Department of Energy. The project was later joined by Total. The goal is the installation of up to ten composite joints in one of the steel risers from the ConocoPhillips operated Magnolia tension leg platform in the Gulf of Mexico, in 4,674 feet of water, by the end of 2004.

For the period under review, work progressed through the design testing phase and preliminary manufacturing activities. Challenges were encountered in the area of secondary seal design, which caused some schedule slippages. Further Finite Element Analysis (FEA) work also led to important design changes, such as increasing the number of traps in the Metal Composite Interface (MCI) and use of different composite layups to meet the required axial and burst capacities. This configuration was tested to 2400 kips in tension (at which level the test fixture, not the composite joint, failed). In burst, the final design verification test was highly successful, with a sample reaching 25,716 psi (over two and a half times the working pressure) after being subjected to an impact energy of 10 kJ.

In parallel to the above testing program, the response of various types of sensors embedded in the composite was measured and compared with measurements recorded by an array of strain gauges on the external surface of the composite. The goal was to identify the optimum system for in-service monitoring of the composite material performance. Strips made of “smart metal” materials, with magnetic properties changing as a function of strain/stress, were selected to be incorporated in the field joints.

As of 30th September 2004, eight full joint steel assemblies have been fabricated and delivered to the composite manufacturing plant. One of the assemblies has been used to fabricate a full scale test joint, with one more test joint still planned. Work was still ongoing to qualify a rubber seal design, as well as additional inspection techniques for the thin steel welds, prior to start of field joints composite manufacturing.

Close Tolerance Liner Drilling

At the beginning of this reporting period, ConocoPhillips had selected Tesco and Baker Oil Tools to help in the work to develop the system. The design work was well underway on the main components of the drilling system. The primary components of the system are 1) the liner hanger, 2) the liner hanger running tool, 3) the Tesco Dynamic Casing SealTM assembly and 4) the liner itself. During this reporting period, this design work was completed, each of the components was built and tested individually, the system was built, and cased-hole and open-hole testing was completed on the system.

All component testing was highly successful. Fatigue was shown not to be an issue with the liner connections selected. The Dynamic Casing Seal assembly was durable and resistant to wellbore fluids and temperatures. The primary components within the liner hanger running tool proved to be resistant to erosion from the circulation during drilling.

The system test was largely successful. The system functioned and tested as designed. During the cased hole testing, the system was thoroughly tripped and rotated: in all respects, simulating an open hole drilling program. It was pulled and examined for wear, and very little was found. However, some internal seals had failed, and that allowed mud to broach the inner assembly. Modifications were made to prevent this in the future and the tool was re-deployed for the open hole test.

In the open hole test, the system was used to drill nearly 300'. It was pulled after the liner became plugged with gumbo. This would not be an issue in the offshore environment where synthetic muds are used to completely eliminate gumbo. Unfortunately, extremely severe vibrations were also encountered on the open hole test which are unrelated to the liner drilling equipment. These vibrations caused sufficient damage to the liner hanger running tool that further testing had to be abandoned.

In January, 2004, it was determined that ConocoPhillips's target deepwater drilling rig, the Transocean Deepwater Pathfinder, was to be released by ConocoPhillips before the liner drilling testing was completed. As such, there was no longer business unit support for the near-term delivery of the technology, and project funding could not be further supplemented to allow for additional testing after the open hole problem. The project was therefore suspended after the open hole test.

In conclusion, the close tolerance liner drilling system works. Minor mechanical enhancements have been identified that must be incorporated to prevent damage from severe vibrations as the test system experienced, and operational changes were developed to avoid the vibrations altogether. Industry interest is moderate at this time, but unless it is dramatically increased, further work on the system will likely not occur. ConocoPhillips is working to generate that interest.

Results and Discussion:

Each of the projects is discussed separately below. This is the last of the technical reports on the Close-Tolerance Liner Drilling system, however.

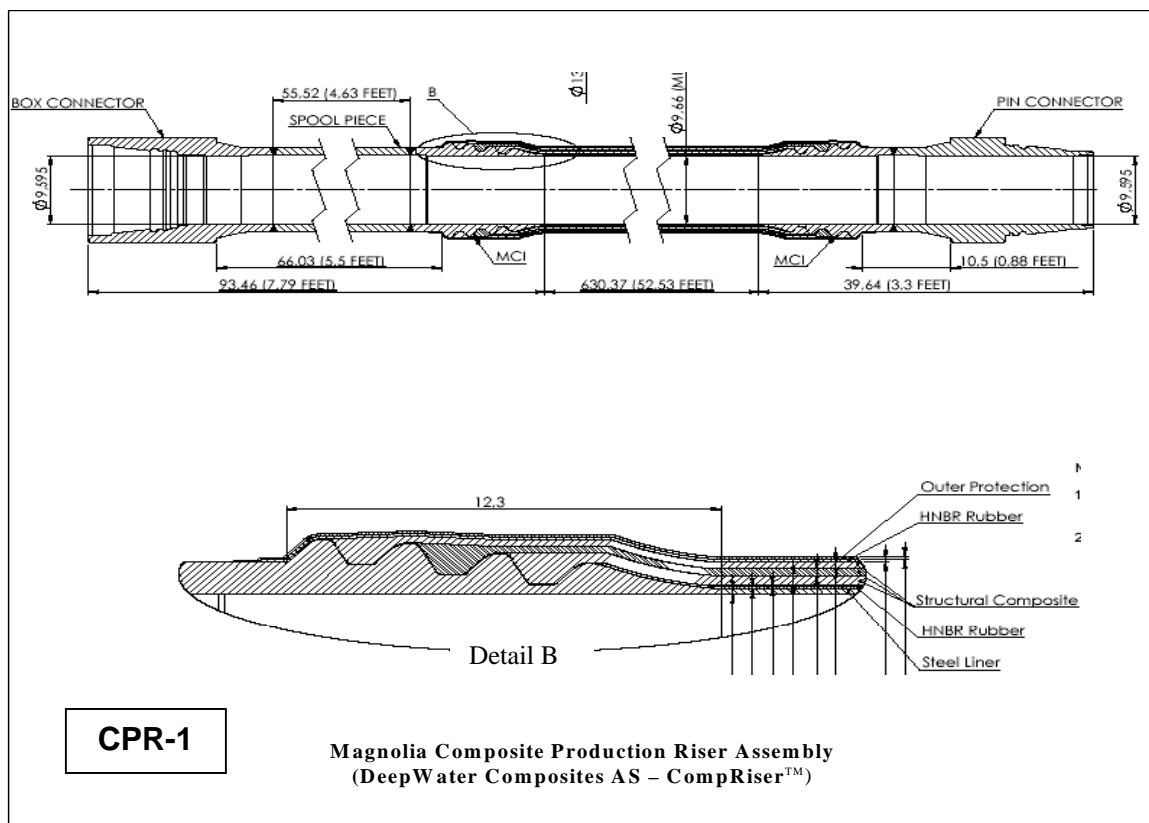
COMPOSITE PRODUCTION RISER DEMONSTRATION :

This section describes the 12-month progress for the Composite Production Riser JIP. A summary of activities is presented first, followed by more detailed technical descriptions of each main aspects: design, testing and manufacturing.

Summary of Activities 4Q '03-3Q '04

As of the start of this review period, an initial composite joint design had been established, and is illustrated below (Fig. CPR-1).

(Refer to previous annual report for detailed description)



Based on this, a first preliminary test sample was fabricated. This sample, CLT-1, was only for the purpose of evaluating the impact of a permeable layer (dry fiber between the inner steel liner and HNBR layer) on the buckling tendency of the inner liner. Given this limited

purpose, cheaper steel forgings were used for the end pieces, with limited quality control performed on the MCI to liner weld, as the test actually called for inducing a crack in the liner. This sample suffered a burst failure during pressure testing. The failure initiated in the steel weld area, followed by failure of the composite overwrap. This highlighted a problem with the original FEA, caused by an erroneous input of the composite allowable stresses.

The FEA was corrected and a second sample (CLT-2) was built. CLT-2 successfully passed the acceptance pressure tests, but, once a crack was manufactured in the inner steel liner, the rubber backup seal failed to hold the 10,000 psi working pressure. The lip seal design had been qualified on a previous project, albeit for a lower pressure. However, being a “pressure energized” concept, it had been assumed to be suitable for a higher pressure. This failure caused a major schedule slippage, as further activities had to be put on hold while a solution was being sought. Manufacturing improvements of the lip seal design were evaluated, as well as an alternative design (the “P” seal). Two new test samples, CLT-3 and CLT-4 were built to test these variations, neither of which proved satisfactory. One of these tests also highlighted the vulnerability of the HNBR liner to high pressure “water jetting” resulting from a small crack developing in the inner liner while under pressure. The water jet actually punched through the rubber in one instance. This prompted a separate study to identify more resistant materials. Tests showed that a secondary steel liner was the only practical option to resist the water jetting effect. Given this, it was then decided that such a secondary steel liner, consisting of a thin (0.049”) metal sheet wrapped and welded around the primary liner would also serve as the backup permeability barrier.

Concurrently to the above activities, DeepWater Composites developed their own FEA model. More detailed analysis indicated that some changes were desirable to ensure that the high axial load requirement would be met. The main changes were the addition of one trap (4 traps instead of 3 traps) to the MCI, and a different composite layup inside the traps (the “hoop insert” design).

At this stage (1Q '04), although a “cracked liner test” still had to be performed to validate the secondary barrier concept (now the steel liner), as well as the effect of the permeability liner, schedule constraints dictated that the main verification testing program be initiated in order to meet the Magnolia Project deadlines. The first three design verification test samples (TS-1-3) were fabricated and shipped to Stress Engineering in Houston. The axial, burst, impact and collapse tests are discussed in detail below. The tests pointed to the need for more refinements in the FEA and some design changes, for burst and impact resistance. Also, at the same time, two “single trap” test samples were built and tested for the sole purpose of validating the FEA axial loading computations.

This first series of tests was concluded in March 2004. As it identified more work to be done from a design and FEA perspective, discussions were held with Magnolia personnel, who indicated that more time was available, with a new riser target installation date in late Summer '04.

Manufacturing procedures for the secondary steel liner were developed. Also, a new rubber seal design, the “S” seal was developed and tested, albeit with unsatisfactory results. A new sample, TS-4, incorporating these new features was tested for impact and burst. This showed that the method used to weld the secondary liner, with a longitudinal weld overlap, adversely impacted the distribution of stresses in the inner composite hoop layers, causing reduced burst resistance. A new manufacturing procedure was then developed to eliminate this problem.

Meanwhile, a CLT-5 sample was built and demonstrated the pressure integrity of the secondary liner, but premature cracking of the primary liner prevented completion of the test on the permeable layer. The next sample, CLT-6, experienced a similar failure.

While additional samples were being manufactured, and again to keep within the Magnolia installation schedule, work started on the metal fabrication for eight full length field joints in July. Thin liners welding took place at SMI/PK Manufacturing in Houston, while the 1” end connector welds were handled by DrilQuip, also in Houston. The eight metal assemblies were delivered to the C4PO composite plant by early August. During that time, the final verification samples (TS-5 and TS-6) successfully met all outstanding impact, burst and axial fatigue requirements. These tests were again performed at Stress Engineering in Houston.

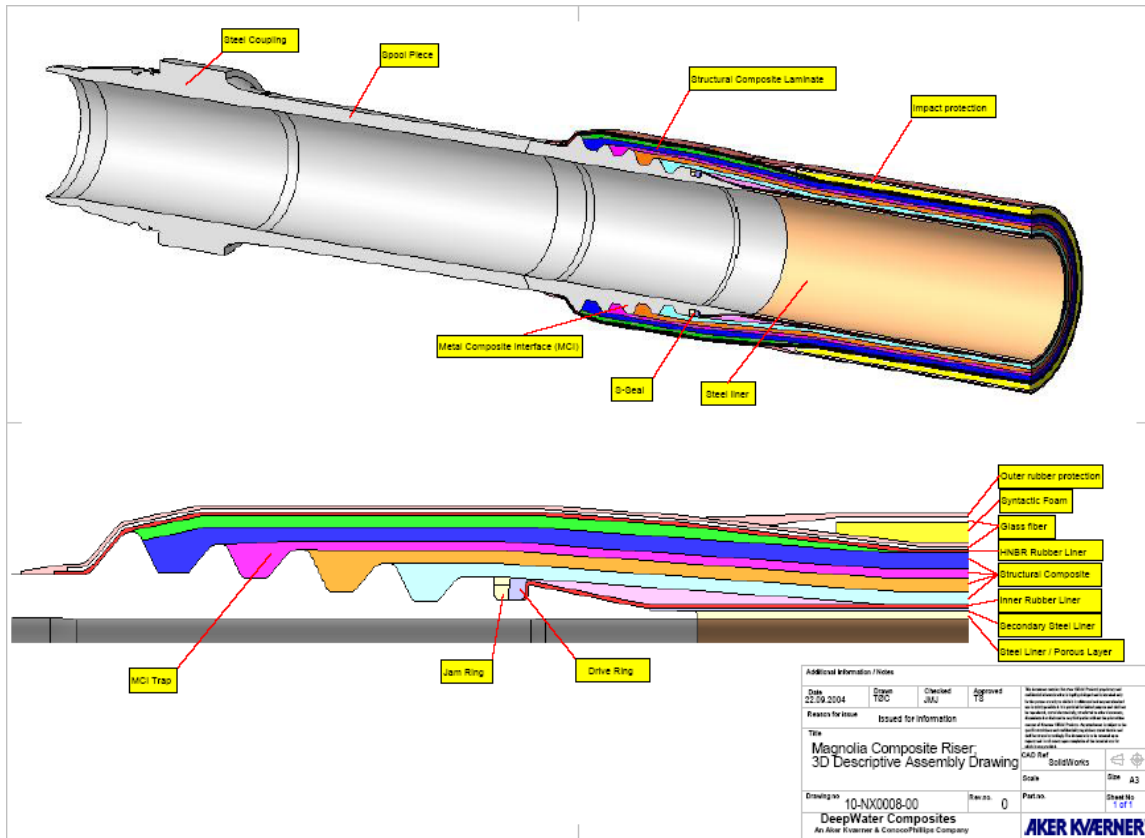
At that stage, the Magnolia installation schedule was revised, postponing the composite joints required delivery to late 2004. It was decided to exploit this extra time to:

1. Complete the cracked liner testing program by manufacturing a new test joint (CLT-7) using one of the production joint metal assemblies. Thus, CLT-7 became the first full scale joint produced, and yielded valuable experience on the peculiarities of filament winding over such a length (over 50 ft), particularly on how to keep the joint straight while rotating, and resulted in some changes to manufacturing procedures. The CLT-7 test was successful in demonstrating the effectiveness of the permeable layer.
2. Initiate work with a rubber seal specialty supplier, Greene Tweed & Co, in Houston, to design and qualify an alternative seal.
3. Reevaluate NDE techniques used to control the quality of the thin steel welds, in light of the problems experienced with the CLT samples. The Alternating Current Field Monitoring (ACFM) system provided by Matrix Inspection and Engineering in Houston, was selected for this purpose.

Work on items 2 and 3 was ongoing as of end of September 2004.

Design and FEA Work

Considerable effort was expended over the period under review to build and calibrate a new FEA model of the composite joint, to better understand the complex interactions between the steel and composite parts. The resulting final design is broadly illustrated below. Note that the composite structure actually consists of alternating multiple hoop and axial fiber layers, as well as fiberglass layers introduced for increased impact resistance.



CPR-2 – Composite joint section (pin end)

The design work consists of three main aspects: Basis of Design, Finite Element Analysis and Global Analysis.

The Basis of Design was produced by ConocoPhillips and establishes the overall design factors and verification test results to be met to satisfy the Magnolia requirements. Essentially, it translates the steel riser design requirements into composite terms. The safety factors of the composite production riser (CPR) joints involve consideration of three factors: 1) the strength-time dependence of the composite structure, 2) the required high reliability of the CPR due to the novelty of application and the lack of plastic deformation, and 3) the acceptable safety factors for steel components. Starting from the maximum loading conditions used for the steel risers, the Basis of Design derives all the safety factors and establishes the minimum design verification tests summarized in the table below.

Qualification Testing Plan

Test	Criterion	Failure mode
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Burst Test, psi	$\geq 21,350$	Tube body
Tensile Strength, kips	$\geq 2,420$	MCI
Axial Fatigue at mean of 700 kips and range of 200 kips	100,000 cycles	No failure
Collapse, psi	2,500	No failure
Impact	10 kJ followed by 10,000 psi pressure	No failure
Cracked internal liner	Identify acceptable depressurization rate	No liner collapse

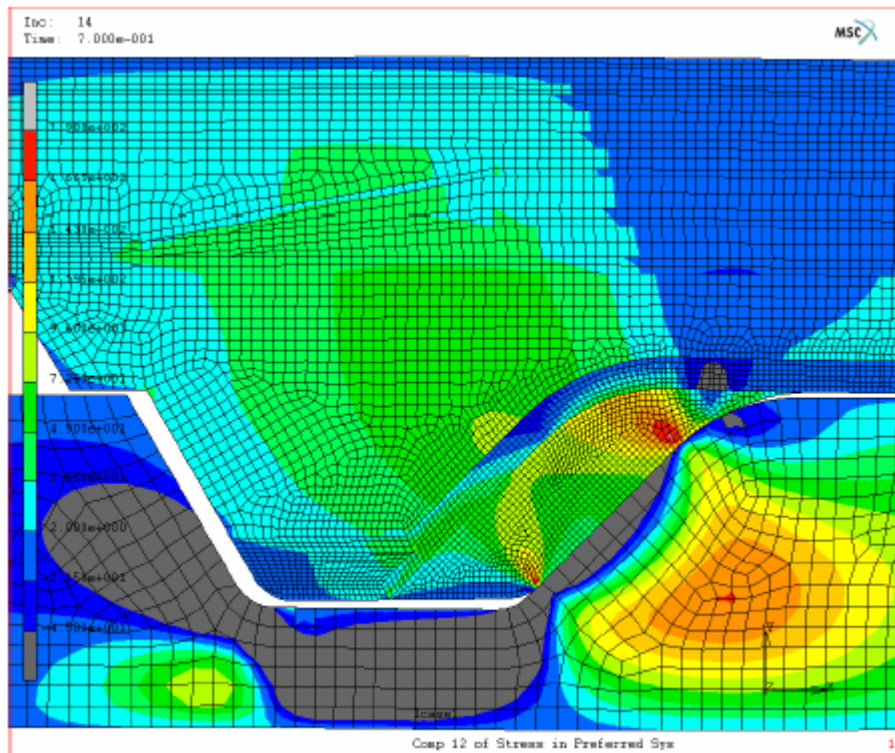
The FEA starts from a given design geometric configuration, builds a finite element computer model, simulates the various loadings (including thermal effects) through the manufacturing and testing process, and, finally, compares the stresses generated by the maximum loading conditions against the materials allowables. The FEA model is checked against prototype test results for validation.

Axi-symmetric, plane strain and 3D models have been developed to evaluate different geometries and load cases. Axi-symmetric models are used to evaluate combined axial and pressure loadings, and are the only ones able to simulate the very complex stress and strain picture at the MCI. The models are able to handle non-linear properties, such as yielding and work hardening of the steel liners, the hyperelastic behavior of rubber, the orthotropic material properties of composites, and non linear contact at the MCI. The axi-symmetric model is unable to include variations in steel liner thickness and ovalities resulting from the “real world” manufacturing process. These parameters are important for the evaluation of localized yielding in the steel liner, stress amplification in hoop fibers, and to predict collapse capacities. A plane strain model was built for these purposes. Finally, a 3D model is used on the cylinder section of the joint to evaluate the impact of the tension loads on the collapse capacity. It is also used to check the collapse capacities generated by the plane-strain model.

This modelling work resulted in several important design changes, namely:

- switch from 3-trap to 4-trap MCI
- introduction of the new “hoop insert” design to decrease composite shear stresses inside the traps
- modification to secondary liner fabrication procedure to obtain a rounder geometry (after the FEA showed the high stress concentrations caused by the weld overlap)

In addition to the FEA work performed by DeepWater Composites, ConocoPhillips also independently contracted to have the original third-party FEA work (initial design) revised and upgraded to reflect the design changes. This independent FEA, using different computer modelling software, essentially confirmed the results obtained by DeepWater Composites.



CPR-3 - Example of FE model mesh

The Global Analysis was performed by ABB-Lummus, the Magnolia Project engineering contractor. It consists of calculating the response of a “hybrid” riser (steel production riser with as number of composite joints inserted) to operational and environmental loading conditions, and determining the required top tensions for the various load cases. Critical cases are then selected to determine the Basis of Design and input into the FEA to verify that allowable stresses are not exceeded. The Global Analusis also confirmed significant reductions in the required top tensions, even for a limited number of composite joints.

Design Verification Testing

A total of 13 full diameter test specimens have been manufactured and tested for verification of the structural properties (TS=Test Sample) and for verification of secondary leak barrier and evaluation of the acceptable depressurisation rate (CLT=Cracked Liner Test). In addition, several small scale samples have been manufactured and tested for preliminary evaluation of specific design parameters. The main results are summarised in the table below. It can be seen that all requirements are met. The verification testing results also validate the accuracy of the FEA predictions.

For the verification test samples (TS), no failure has occurred in any of the welds during destructive testing. However, cracks were discovered in the secondary liner to MCI weld in the CLT-7 joint (first full length joint) during post test examination. This discovery has

prompted a re-examination of all liner welds using a more sensitive technique (ACFM). This process was still underway at the time of this writing.

The testing of the verification test samples (TS) was carried out by Stress Engineering Services (Houston) and the Cracked Liner Testing (CLT) was performed by C4PO (Sacramento).

Verification Testing Summary Table

Test	Requirement		Result		
	Criterion	Failure mode	Obtained	Failure mode	Test Sample
Burst Test, psi	$\geq 21,350$	Tube body	25,716 (after 10kJ impact)	Tube Body	TS-5A
Tensile Strength, kips	$\geq 2,420$	MCI	2,400 for 18 minutes	Test fixture failure	TS-1
Axial Fatigue at mean of 700 kips and range of 200 kips	100,000 cycles	No failure	102,868 cycles	No failure	TS-6
Collapse, psi	2,500	No failure	2,500 (after 10kJ impact)	No failure	TS-3
Impact	10 kJ followed by 10,000 psi pressure	No failure	10 kJ followed by 10,000 psi pressure	No failure	TS-5A
Cracked internal liner	Identify acceptable depressurization rate	No liner collapse	Depressurization rate > 2000psi/min	No liner collapse	CLT-7

Prior to the verification testing, all test samples have been proof tested by applying internal pressure. The test consists of 2 - 3 pressure cycles to 11,250 psi and a hold time of 5 or 15 minutes. All specimens were instrumented with strain gauges in hoop and axial direction and a thermocouple. Some were also instrumented with axial displacement transducers. Additional sensors, including fibre optics, accelerometers and embedded metallic sensors were also monitored as part of the in-service monitoring evaluation program. Without exceptions, the results from the FAT pressure testing showed consistent behaviour between the samples in terms of volumetric expansion under pressure and strain behaviour. This proves consistency of the manufacturing.

The above test results compare to the following FEA predictions:

- Burst: >23,644 psi
- Axial: >2,500 kips

A total of 3 test samples have been tested for burst pressure. The first burst sample (TS-2) failed earlier than predicted. After a thorough investigation it was found that the structural composite contained “waviness”, i.e. the fibres were not properly aligned. As a result, more hoop fibres were added to the design. In the meantime, the Cracked Liner Testing revealed a need for a secondary steel liner. This was implemented in TS-4. When testing TS-4, the

longitudinal weld of this secondary liner caused premature failure. The reason being that the weld overlap gave a “flat spot” in the structural composite causing stress concentrations and premature failure. The overlap in the secondary liner was removed on the next burst sample, TS-5A, that was successfully burst tested to 25,716psi after a 10kJ impact, meeting the Magnolia requirement and validating the accuracy of the FEA predictions.

To meet the axial strength requirement, a four-trap test sample (TS-1) and two single trap specimens (1 and 2) were tested. The results are summarised in the table below. During the first axial test of the four trap test sample TS-1, the test fixture weld failed after 18 minutes at 2,400kips. When studying the strain data from the test it can be seen that the test sample would have survived the anticipated test programme of 100hour hold time at 2400kips and 2500kips ultimate failure load. To show the resilience of the composite riser design, the fixtures were re-welded and the sample tested again. The re-test gave an ultimate axial strength of 2,358kips /4/. This was an excellent result, taking into account that the test sample had been subjected to a very high shock load after the first test.

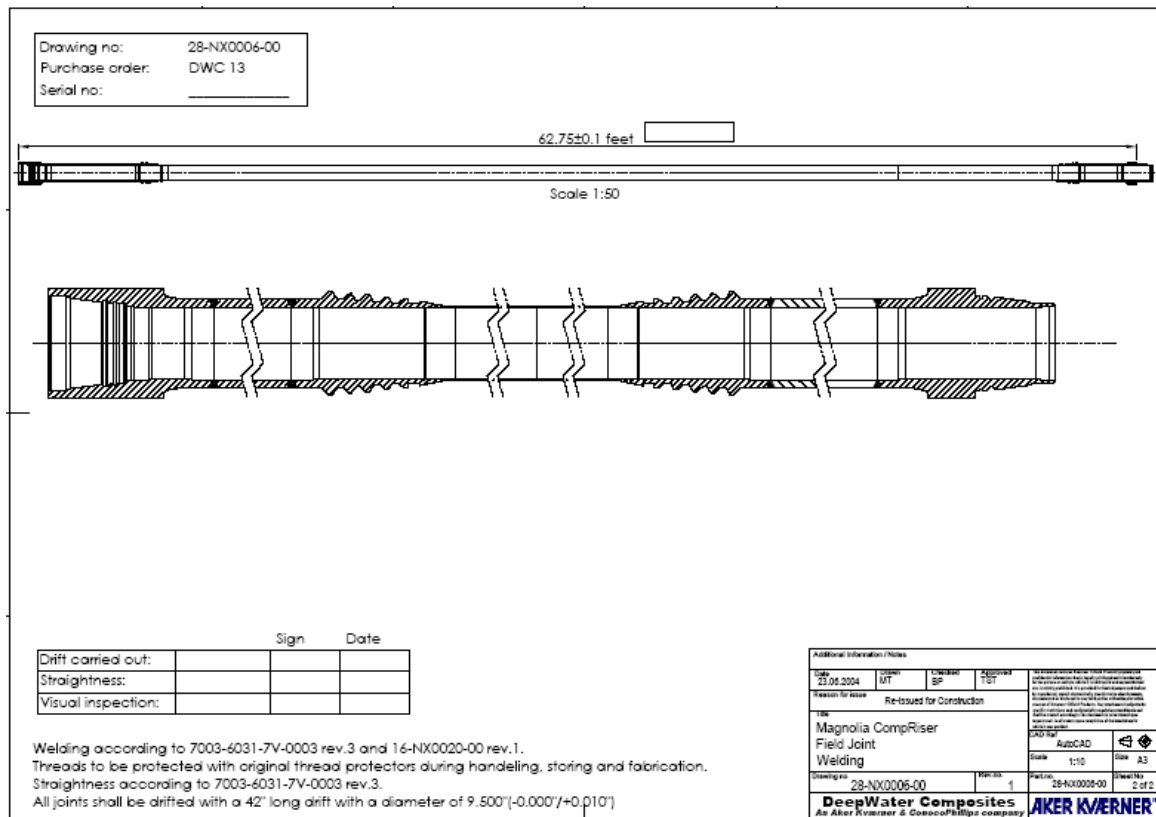
In order to verify the predicted axial capacity improvement by introducing the “Hoop Inserts” into the MCI design, two single trap specimens, one with hoop insert and one without hoop inserts, were manufactured and tested. The test sample with hoop inserts had a much higher axial capacity (704kips) compared with the test sample without hoop inserts (498kips). It can also be seen that the displacement/creep during the 2 hour hold at 325kips is much less for the hoop insert sample. Hence, it was verified that the hoop inserts improve the ultimate axial capacity and reduce the creep (static fatigue).

Axial testing summary

Test Sample	Load [kips]	Hold time [minutes]	Failure mode	Comments
TS-1	2,400	18	Weld failure in test set-up	Failure in test set-up. By studying the strain data it is very likely that the sample would have survived the planned 100 hours at 2400kips and ultimate strength of 2500kips.
	2,358	-	Composite shear in MCI	Test performed after 87kJ shock load due to weld failure in test set-up. Failure occurred as composite shear in MCI.
Single Trap 1 - No hoop inserts	325	120	Survival	Displacement: 0.028”
	498	-	Composite shear in MCI	
Single Trap 2 - Hoop inserts	325	120	Survival	Displacement: 0.018”. This is 64% of what was observed for Single Trap 1.
	550	600	Survival	Displacement: 0.036”
	704	-	Composite shear in MCI	

Manufacturing

Field joint metal assemblies were fabricated and the first full scale joint (CLT-7) was completed, except for the outer protective layers, during the period under review. Below is a drawing showing the metal assembly for a full joint (CPR-4)



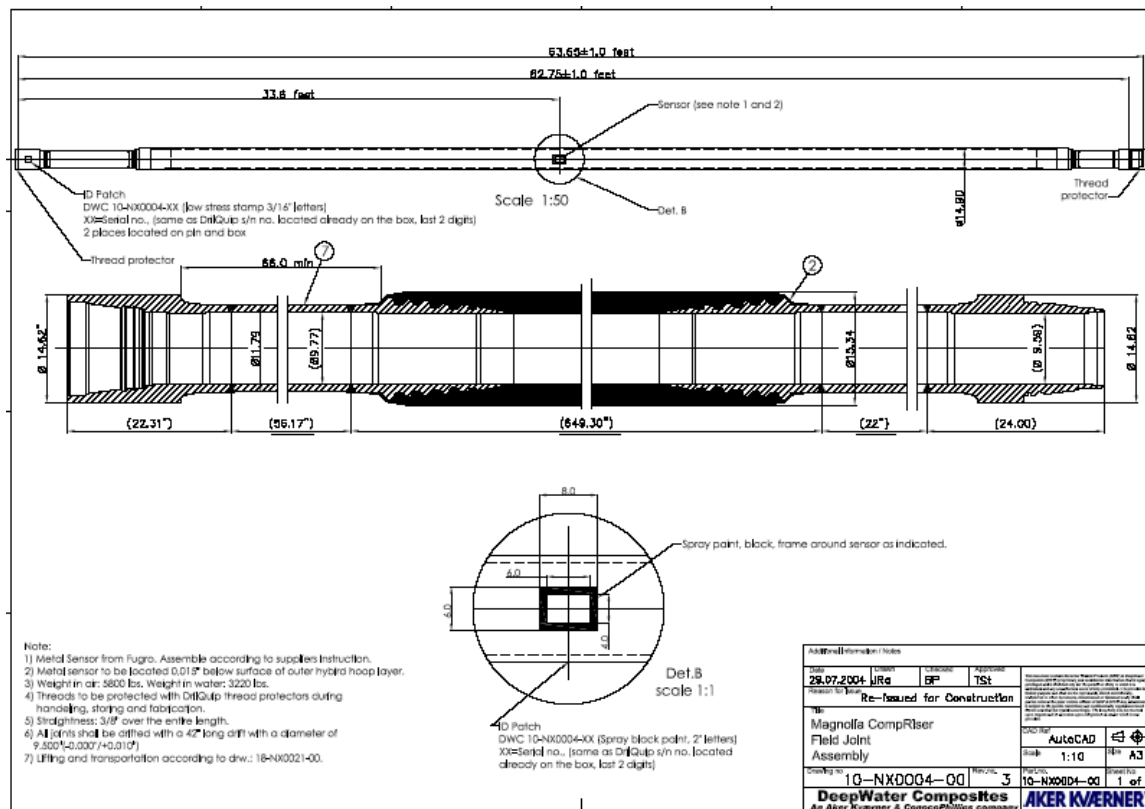
CPR-4 – Metal assembly

For a field joint, the main fabrication steps are:

1. Machining of MCI's (two per joint), pin and box connectors from A707 forged steel.
2. Welding of box/pin, short 1" wall pipe spoolpiece (for handling purposes) and MCI.
3. Welding of primary steel liner from MCI to MCI (0.165" WT, 85 ksi material).
4. Pressure testing of assembly to 2300 psi.
5. Wrapping primary liner with dry fiber layer (permeable layer).
6. Wrapping and welding secondary steel liner (0.049" WT, 30 ksi). This comes in 8 ft long sheets that are wrapped around and welded in sections using longitudinal and circumferential backing strips. Helium test welds (secondary/backup seal).
7. Sand blasting of outer steel liner surface.
8. Spray layer of Polyurea around liner, from one MCI seal groove to the other.
9. Machine Polyurea in each seal groove to accommodate rubber seal.

10. Install rubber seals (seals off Polyurea against steel tube – “tertiary” seal).
11. Build up structural composite through first trap. For axial fibers, strips of pre-impregnated (with resin) fibers are run from one trap to the other. Hoop fibers are applied by filament winding of individual fibers around the tube and into the traps (to lock in the axial strips). The entire joint is rotated during filament winding, with a filament machine moving up and down the length of the joint, applying the hoop fibers under constant nominal tension.
12. Intermediate partial curing of the first trap composite. The whole joint is placed in an oven, and the fiber/resin matrix is partially cured in order to stiffen the whole assembly and minimize bending fatigue of the thin liner welds during filament winding of the remaining three traps.
13. Build composite on the remaining three traps, as for the first one.
14. Apply HNBR layer over tube and MCI sections (outer seal to prevent seawater ingress into the composite)
15. Final curing in oven (350 deg F).
16. Apply outer protective layers (one Polyurea layer, fiberglass, impact foam and one more Polyurea layer).
17. Factory acceptance testing (drift and two 11,250 psi pressure cycles).

The final product is depicted in the drawing below (CPR-5).



CPR-5 – Completed composite riser joint

Some of the fabrication steps are illustrated in the following photographs taken at various stages of the process (CPR-6 to 17)



CPR-6 - Pin/MCI assembly fitted to primary liner



CPR-7- Secondary liner section being wrapped over primary liner, dry fiber and backing strips



CPR-8 - Secondary liner welds



CPR-9 - Completed metal assembly loaded onto winding cart



CPR-10 - Spraying Polyurea layer



CPR-11 - Polyurea machined into seal groove



CPR-12 - Rubber seal clamped in groove



CPR-13 - Pre-preg axial fiber strips applied



CPR-14 - Hoop fiber filament winding



CPR-15 - Composite application complete



CPR-16 - Impact protection foam installation



CPR-17 - Completed joint

CLOSE TOLERANCE LINER DRILLING (CTLTD):

Tesco Corporation and Baker Hughes were selected as the primary contractors to provide the components necessary for the CTLTD system and had progressed the designs of the major components considerably at the beginning of this reporting period. The summary basis of design is:

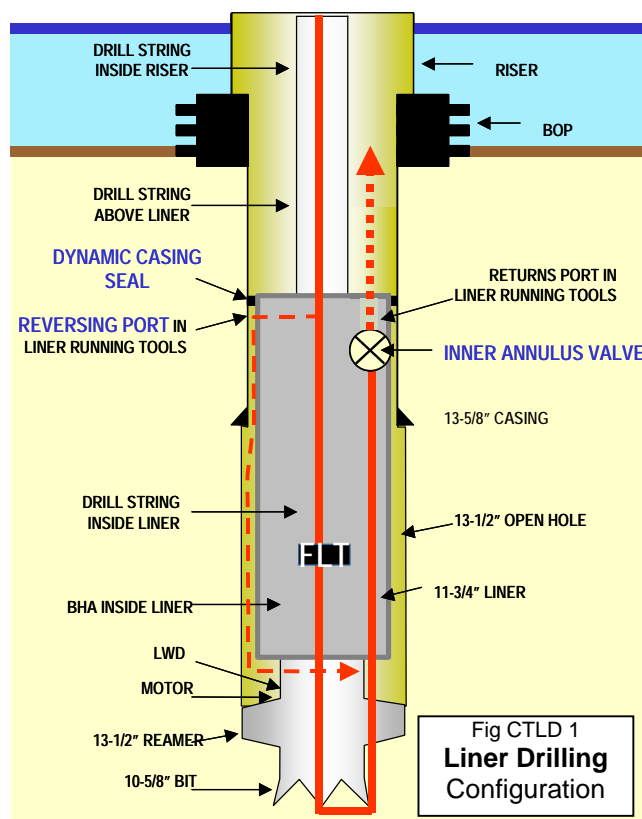
- 11-3/4" OD liner run inside of 13-5/8" casing (12.375" ID).
- 5000' length,
- Setting depths to 25,000',
- Directional drilling capability,
- Formation evaluation (Logging while drilling capability), and
- Synthetic based drilling mud.

The directional drilling and logging while drilling requirements require that the liner have a drilling assembly hanging below it, similar to the way that the onshore casing while drilling is done. The annular clearance between the liner and the casing is so tight, that it would be impossible to circulate mud returns up this annulus without fracturing the exposed formation. Therefore, the design also requires that returns come up the inside of the liner.

Meeting these two broad requirements requires that the drill pipe be run through the liner with the drilling tools hanging below it.

Consequently, the liner is hung from the liner hanger and is not exposed to the drilling torque. Circulation ports were designed into the liner hanger to accommodate the mud returns.

There are two other requirements that impact the design: the desire to sweep the open hole annulus of any cuttings, debris or influx materials, and the need to address a well control incident when the liner and drill string are across the BOP stack. To meet the first requirement, a reverse-circulation port was built into the liner running tool, and it is ported to divert a small portion of the mud from the drill string down the backside of the liner. This can only be done with the introduction of a seal at the top of the liner hanger that forces the



mud to go down the tight annulus rather than directly out above the liner top. This is Tesco's "Dynamic Casing Seal™" (DCS) element. To meet the second requirement, Baker developed an "Inner Annulus Valve™" (IAV) had to be built into the running tool that allowed rapid closure of the liner by drill pipe annulus when needed. This isolates the drilling riser from the conduit through the liner to the wellbore below the blowout preventer.

Testing:

The new liner drilling system must be exhaustively tested before it will be used offshore. There were three test phases: component testing, cased hole system testing and open hole system testing. The goals for the overall testing program were:

- Prove that the DCS seal integrity is maintained after tripping into the well for 15,000' and while drilling for the subsequent 5000'. Prove its tolerance to drilling fluids and temperatures used in deepwater drilling applications.
- Prove that the liner hanger and packer can withstand the loads and conditions associated with drilling 5000'. Of significant concern was the internal erosion of the extrudable ball seat, used to set the liner hanger after the drilling was complete.
- Prove that the liner can withstand the cycles associated with rotating for that same duration, even at relatively severe curvatures (doglegs).
- Prove that the IAV and reverse-circulation port and valve maintain their integrity over this duration.
- Understand the unique hydraulics associated with this system. Especially challenging are the surge and swab characteristics of the system.

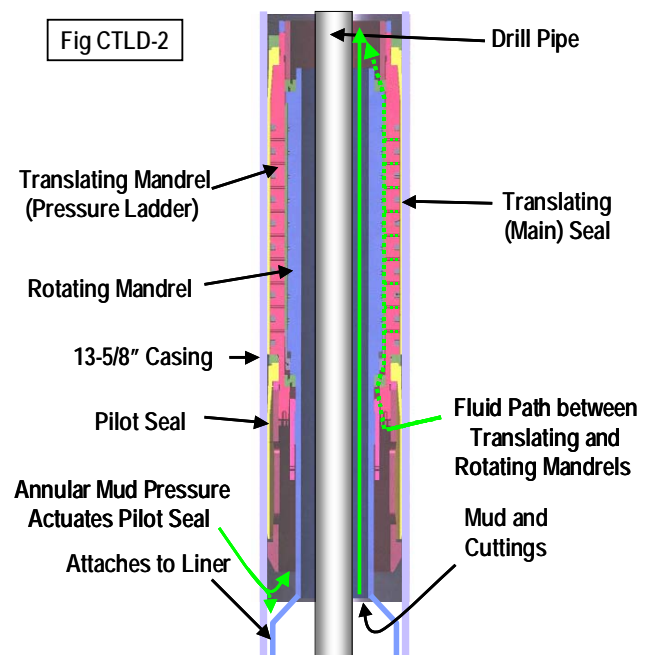
Each of the testing programs and results are discussed.

Component Test Results:

Dynamic Casing Seal:

The DCS is a labyrinth seal consisting of a pressure ladder between a rotating inner mandrel and a stationary outer translating mandrel. The seal element is positioned on the outer mandrel and actuated by the pressure from behind it in the pressure ladder (Fig CTLD-2).

A small-scale seal was built and placed in a casing section and then immersed in a tank with synthetic based mud (Fig CTLD-3). Mud was circulated through the seal as it was being rotated within the mud. It was found that the seal



easily endured the bearing loads and the circulating temperatures to 250° F, at 30 to 90 rpm for 300,000 revolutions. The seal assembly was also tripped up and down Tesco's test wellbore for 19,000' to test its wear resistance. Again, the seal performed as designed.

Liner hanger and liner hanger running tool:

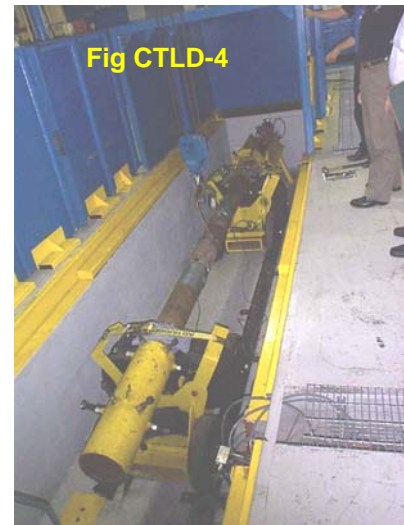
The liner hanger used is a modified version of the widely-used Baker INLine™ liner hanger and ZX packer, so extensive component testing was not required. The one component that did require additional testing was the extrudable ball seat. This receptacle is used to catch and seal against a dropped ball in order to shift a sleeve to expose the liner hanger setting tool hydraulics passages. It had not been used in an extended circulation path before, so ball seats made of four different materials were tested in a flow loop where 14.5 ppg water based mud was circulated at 500 gpm for 170 hrs. One of the seats showed no significant wear, and it was selected for the new liner hanger running tool.



Liner:

Of concern were the fatigue consequences on the liner while drilling, especially in the connector area. The connectors chosen were flush or near-flush OD: Hunting's SLSF and Grant-Prideco's DWC-DS/A. To test this, a "bouncing betty" was used (Fig CTLD-4). It is an oscillating machine into which pipe can be placed and rotated with induced lateral loads, creating a curvature in the center of the pipe.

Three samples of each connection were tested to failure under an induced stress equivalent to a relatively severe 5°/100' dogleg severity. The samples all failed between 2.7 and 6 million cycles: in all cases, at least 10 times the goal. Both were deemed acceptable for use offshore.



Cased Hole Testing:

Upon successful component testing, the system was assembled and delivered to Tesco's test rig in Houston. The goals of the cased hole testing were:

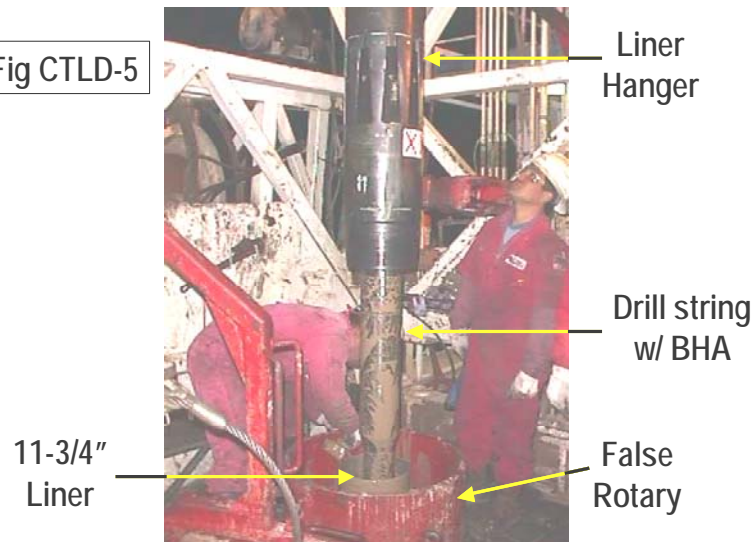
- Simulate the wear experienced while tripping the assembly into a 19,000' deep well in deep water.
- Simulate the wear experienced while drilling 5000' of open hole.
- Verify the ability of the tools to function after being exposed to the above.
- Test the robustness of the liner connectors for repeated make-up and break-out.

- Determine the vibrational characteristics of the system.
- Understand the hydraulic characteristics of the system.
- Improve the handling procedures for offshore use.

In the cased hole test, the liner was run and hung off in the false rotary. The drilling assembly was run without the concentric reamer or mud motor through the false rotary (Fig CTLD-5).

The liner hanger, liner hanger running tool and DCS assembly were picked up and made up into the liner. The BHA included the downhole drilling dynamics package (Baker's CoPilot™ tool) and annular pressure equipped MWD. These devices would be used to measure any vibrations and the pressures necessary to understand the hydraulic characteristics.

Fig CTLD-5



The liner drilling assembly was tripped in and a series of pumping, tripping and reaming operations were performed to gather the pressure and vibration information. In all, the system was rotated about 100,000 revolutions, or about 1/3 of an offshore drilling job.

After pulling out the assembly and returning it to the shop, the ball was dropped and the liner hanger set, proving that the mechanism is robust. External inspection indicated no significant wear anywhere (Fig CTLD-6). Upon tear-down, however, there were some negative findings that were addressed. The most significant was the failure of a seal in the liner hanger running tool. This allowed mud into the running tool, and the barite in the mud settled out within the tool, locking up some of the mechanism (Fig CTLD-7). This was redesigned so that the mechanism was contained in a pressure-balanced oil bath. The DCS seal had several missing wear inserts (Fig CTLD-8), so the shape of these inserts was changed from cylindrical to spherical. The liner was also inspected, and several joints required recutting.

Open Hole Testing:

The redesign and re-manufacturing required about 2-1/2 months. Afterwards, the equipment was remobilized to the Tesco rig, and the open hole testing program began. The objectives of the program were:

- Demonstrate that the system, with its novel circulation path, can drill open hole.

- Determine whether the improvements made to the tools and handling practices were effective.



Mud Filter of DCS

Translating Seal
Of DCS



Liner Hanger
Slips



Fig CTLD-6



Fig CTLD-7



Fig CTLD-8

After running the 11-3/4" liner in the well, the same BHA was picked up and run through the liner as in the cased hole test, except that the specially developed 13.5" Smith Rhino Reamer and a mud motor were picked up to allow the hole enlargement for the liner at relatively low liner rotation speeds. The liner hanger running tool, liner hanger and DCS assembly were picked up. (Fig CTLD-9).



The assembly was run into the well and drilling commenced. The first step was to open up the rathole beneath the 13-3/8" casing. When the pumps and rotary were first engaged, there were severe vibrations. Shortly thereafter, metal shavings were found in the shale shaker, confirming that the 13-3/8" casing was about 20' deeper than originally thought and that the Rhino Reamer concentric reamer had been opened too early. The assembly was slacked off to below that and the pumps were re-engaged. The drilling was quite smooth then.

In the following 44 hours, drilling continued to only 2595', some 289' deeper. The penetration rates varied considerably from 100 ft/hr in the sands to 2 ft/hr in the shales. This was due to the extraordinary amount of gumbo that was encountered. The drilling parameters were varied from 30 to 60 rpm, and the pump rates varied from 380 to 520 gal/min. There were numerous drilling problems with blinding the shaker due to too high a flowrate and too many solids. At the end of the day, the gumbo won the fight and the return flow stopped, indicating that the tools had plugged up with gumbo. The assembly was tripped out of the well.

The tools were totally plugged up with gumbo, as expected. The outside of the tools was clean, reinforcing the fact that the reverse circulation feature works in keeping the backside of the liner clean (Fig CTLD-10).

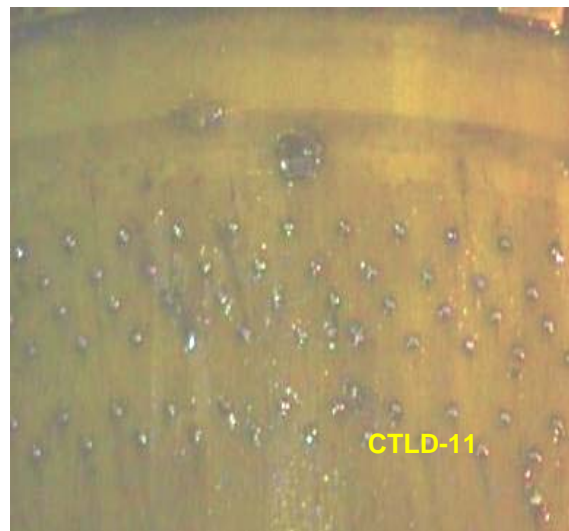


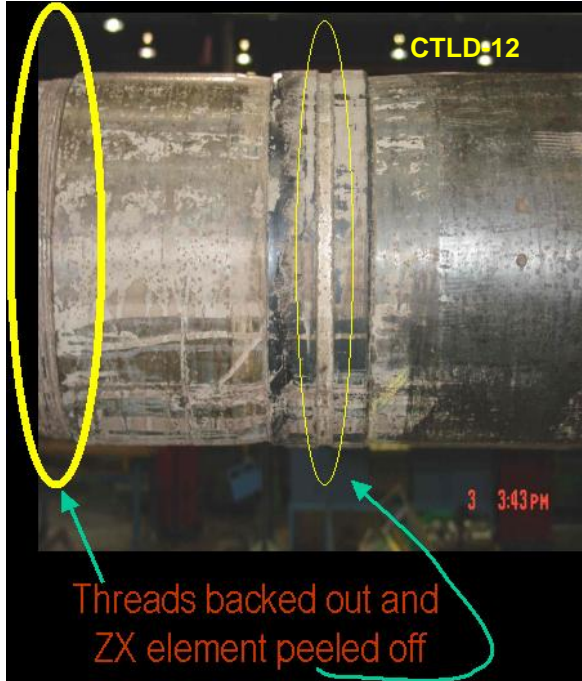
What was surprising is that nearly every shear pin in the running tool had sheared, allowing several sleeves to translate up or down the liner hanger. This was due to the shock loads experienced when the Rhino Reamer was opened up inside of the casing.

The tools were sent to the shop for teardown, but before doing so, the ball was again dropped, and again, the liner hanger set.

Upon examination in the shop environment, the following observations were made:

- The changes to the inserts in the DCS element worked perfectly; none was lost (Fig CTLD-11).
- A ZX seal element had been peeled off through contact with the casing wall. The cause was the translation of the setting cone when the vibrations sheared the set pins (Fig CTLD-12).
- There was erosion on the inside of the outer closing sleeve over the reversing port. This occurred because the vibrations allowed the set pins holding the sleeve in place to vibrate loose, and the sleeve began closing on its own across the reversing jet.





prevent its occurrence.

Post-Mortem Summary:

Though extremely disappointing at the time, it was beneficial that the assembly was subjected to such unusually severe loads and conditions. All of the lessons learned here were much easier to accept than they would have been had the tools performed flawlessly, only to find the same weaknesses in the \$400,000 per day deepwater offshore environment. As it turned out, all of the observations made are easily addressed with minor re-design to avoid their happening again. Additionally, operational practices have been developed which allow extremely rapid detection of a prematurely opening concentric reamer. Further, the gumbo issues in deepwater are virtually non-existent, as synthetic based muds used completely

Hydraulics and Vibrations Analysis:

The data from the Co-Pilot tool was downloaded and analyzed following each of the tests. The hydraulics data collected was used to modify and validate the MI Drilling Fluids Virtual HydraulicsTM modeling software. This software is certainly one of the industry's premiere hydraulics models, and it is widely used by most operators in deepwater. Now, the software can be used to size the reversing jet and accurately predict the hydraulics profiles in the well.

The vibration data was analyzed, and except for the vibrations caused by opening the Rhino Reamer too soon, they were all found to be well within the safe operating limits of the drill string and delicate BHA components.

Drilling Operations and Well Control:

Clearly, the equipment is not beneficial if there are not effective, efficient procedures in place for its safe use. Most importantly are the safety related aspects, and the top of that list is well control assurance. The Inner Annulus Valve was included for the well control case in which the subsea BOP is closed around the liner during a well control event (Fig CTLD-13). By rotating the drill string a few turns to the left, this valve would then be closed, isolating the ID of the liner from the drilling riser.

This valve could not be tested in the cased hole test, as the barite had already settled out in the mechanism and it could not be closed. The modification was made to protect this mechanism between the cased and open hole tests, and the IAV was successfully closed and pressure tested to 200 psi during the open hole test.

From an engineering standpoint, Argonauta Drilling Services, L.L.C., was contracted to perform well control modeling on various kick scenarios. They modeled drilling kicks at 19,193' and 24,193', swabbed kicks behind the liner, swabbed kicks while taken out of the hole and helped develop various well control procedures. To summarize, the well control aspects are essentially the same as for conventional drilling in deepwater.

The operational procedures while drilling are slightly different than from conventional drilling. As examples:

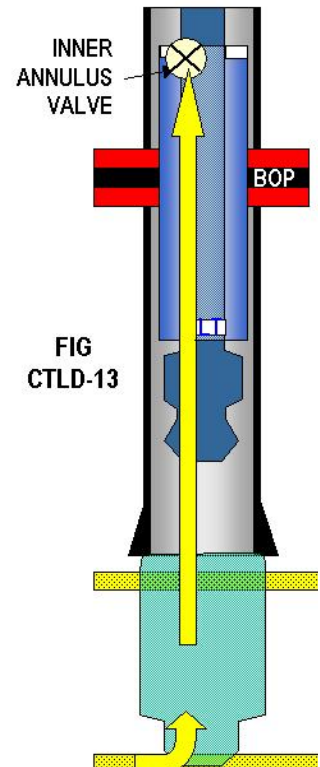
- One must be very careful to control rotary accelerations and decelerations, as the mass and inertia of the liner is quite significant. It was found that several joints of liner broke out at much less torque than they were made up with, and this is due to the momentum of the liner working to break the connections when the liner rotation is being stopped.
- Hydraulics are much more complex due to the fluid being diverted from the drill string at the top of the liner. This must be modeled so that the bit, concentric reamer and reversing jets can all be properly sized. Virtual Hydraulics can now do this.
- The inner drill string and BHA that goes through the liner is run through a false rotary table, which is not conventional equipment on the drilling rig. The mass of this inner string is difficult to handle when the fine threads of the liner hanger are being made up into the top joint of liner. A coarse-threaded "liner saver sub" was designed and built to facilitate that. It worked perfectly.

In short, the procedures are different, but they are not challenging.

Advertising our work:

From the outset, it was not intended that the Close Tolerance Liner Drilling be solely for ConocoPhillips. It was to be developed for the benefit of Industry. As such, a concerted effort was made to keep Industry informed of the progress. Several presentations were made and several articles were written. Among them:

- March, 2003: World Oil Casing Drilling Conference, Houston.
- December, 2003: IADC Gulf of Mexico Conference, Houston.



- December, 2004: Minerals Management Service, New Orleans
- January, 2004: Managed Pressure Drilling Conference, Galveston.
- February, 2004: Natural Gas Technologies Conference II, Phoenix.
- February, 2004: Deepwater Operators Group Meeting, New Orleans
- February, 2004: Drilling Contractor Magazine
- March, 2004: World Oil Casing Drilling Conference, Houston.
- June, 2004: Drilling Engineering Association (Europe), Vienna.

Conclusion

The Composite Production Riser has proven to be more technically challenging than originally expected. However, it is important to note that most of the difficulties encountered are related to matters other than the structural composite (namely, thin steel liner welding and high pressure rubber seal), and can be readily overcome. The project has been highly successful in qualifying the composite structural design for the very high loadings typical of a steel riser. Since a full composite riser string, as opposed to just a few joints inserted in a steel riser, will be much lighter, loading conditions for full field applications will be much lower. This program has removed any outstanding doubt on the applicability of the composite riser technology for deepwater application. Progress remains on track for the delivery of 4-6 field joints to the Magnolia Project by late 2004.

In early 2004, ConocoPhillips announced the end of its deepwater drilling program and released the Deepwater Pathfinder, the drillship that was completing its long-term contract with the company. With the end of its deepwater efforts came the end of the focus on deepwater technology, as well as further funding of projects like the Close Tolerance Liner Drilling project. However, the sharing of the progress of this project has been extensive, and other operators have shown interest in picking up the work and continuing on. Those discussions are ongoing at this time.

DOE Award Number: DE-FC26-00NT40964

Invoice No.	From	Through	Project* (SSP/CPR/CTLD)	Conoco or ConocoPhillips	Kvaerner	Chevron Texaco	Period Expenditure	Cumulative Project Expenditure	Period DOE Reimbursed	Cumulative DOE Reimbursed	Percent Industry Match	DOE Budget or Cap Increase	DOE Balance
1	Oct, 2000	June, 2000	SSP	\$ 324,458.78	\$ 170,338.50	\$ -	\$ 494,797.28	\$ 494,797.28	\$ 164,932.43	\$ 164,932.43	66.7%	\$2,000,000.00	\$1,835,067.57
2	June, 2000	Sept, 2001	SSP	\$ 42,594.59	\$ 238,876.81	\$ -	\$ 281,471.40	\$ 776,268.68	\$ 93,823.80	\$ 258,756.23	66.7%		\$1,741,243.77
3	Oct, 2001	Aug, 2002	SSP	\$ 361,784.72	\$ -	\$ -	\$ 361,784.72	\$ 1,138,053.40	\$ 120,594.91	\$ 379,351.14	66.7%		\$1,620,648.86
4	March, 2003	Dec, 2003	CPR	\$ 762,867.34	\$ 177,421.25	\$ 90,000.00	\$1,030,288.59	\$ 2,168,341.99	\$ 515,144.29	\$ 894,495.43	58.7%	\$ 100,000.00	\$1,205,504.57
5	Jan, 2003	Sept, 2004	CTLD	\$ 2,338,365.51	\$ -	\$ -	\$2,338,365.51	\$ 4,506,707.50	\$ 300,000.00	\$ 1,194,495.43	73.5%		\$ 905,504.57
6	Jan, 2004	Sept, 2004	CPR	\$ 2,529,391.03	\$ 296,774.73	\$ -	\$2,826,165.76	\$ 7,332,873.26		\$ 1,194,495.43	83.7%		\$ 905,504.57
							\$ -	\$ 7,332,873.26		\$ 1,194,495.43	83.7%		\$ 905,504.57
				\$ 6,359,461.97	\$ 883,411.29	\$ 90,000.00	\$7,332,873.26		\$ 1,194,495.43		83.7%	\$2,100,000.00	\$ 905,504.57

* Note: SSP = Subsea Processing, CPR = Composite Production Riser, CTLD = Close Tolerance Liner Drilling